A Chinese Electron-Ion Collider

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Outline

- **Introduction**

HIAF facility at IMP

- **EIC@HIAF Physics**

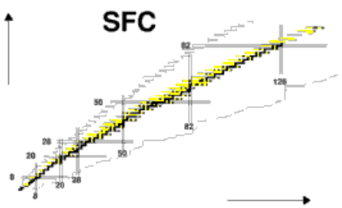
Nucleon spin-flavor structure (polarized sea, Δu, Δ d, Δ s)
3D structure: GPDs (DVCS & DVMP)
3D structure: TMDs (sea, wide range in Q^2, P_T)
Meson (pion/Kaon) structure function at high-x
Hadronization/EMC/SRC measurement

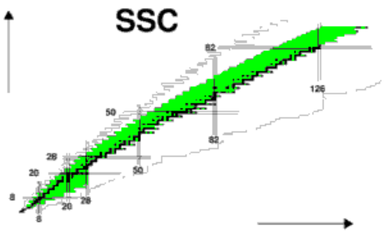
- **Current Status and Summary**

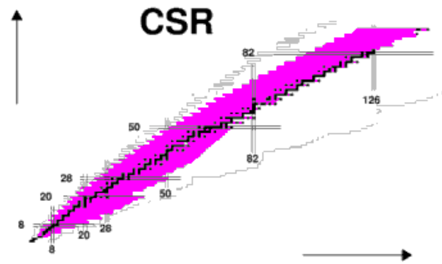
EIC@HIAF detector design
IMParton proton PDFs & nuclear IMParton (nIMParton)
Nuclear dependence of the EMC effect & N-N SRC

IMP Facilities History

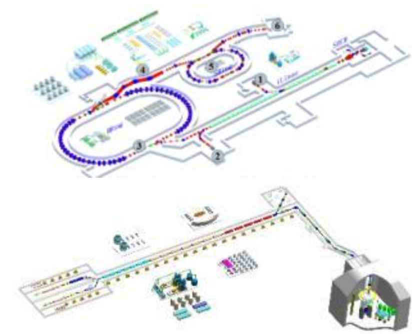
1958 1976 1996 2015





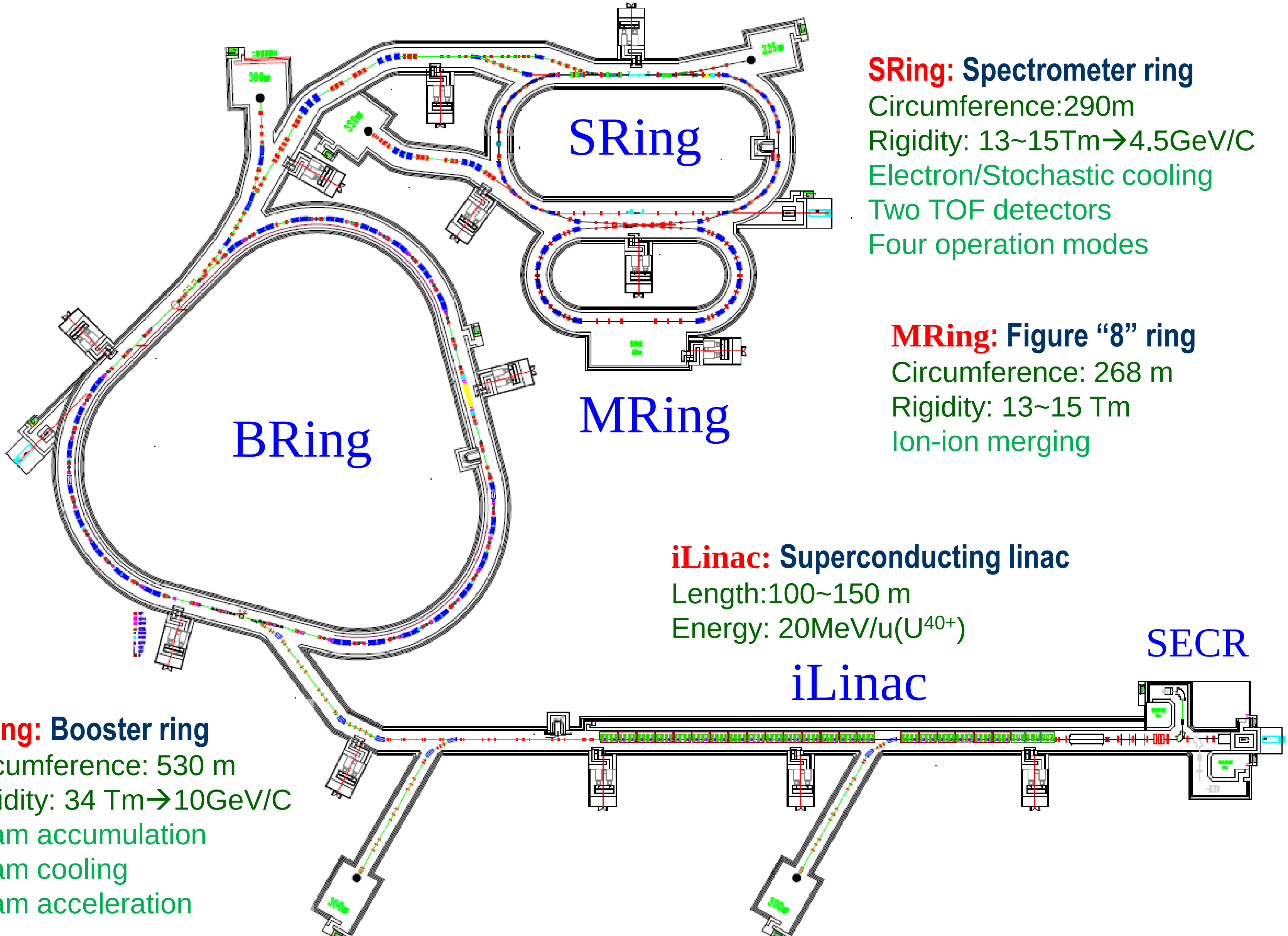


HIAF



HIAF：High Intensity Heavy Ion Accelerator Facility

HIAF(Phase I) Main Parameters



SRing: Spectrometer ring
Circumference:290m
Rigidity: 13~15Tm→4.5GeV/C
Electron/Stochastic cooling
Two TOF detectors
Four operation modes

MRing: Figure "8" ring
Circumference: 268 m
Rigidity: 13~15 Tm
Ion-ion merging

iLinac: Superconducting linac
Length:100~150 m
Energy: 20MeV/u(U^{40+})

BRing: Booster ring
Circumference: 530 m
Rigidity: 34 Tm→10GeV/C
Beam accumulation
Beam cooling
Beam acceleration

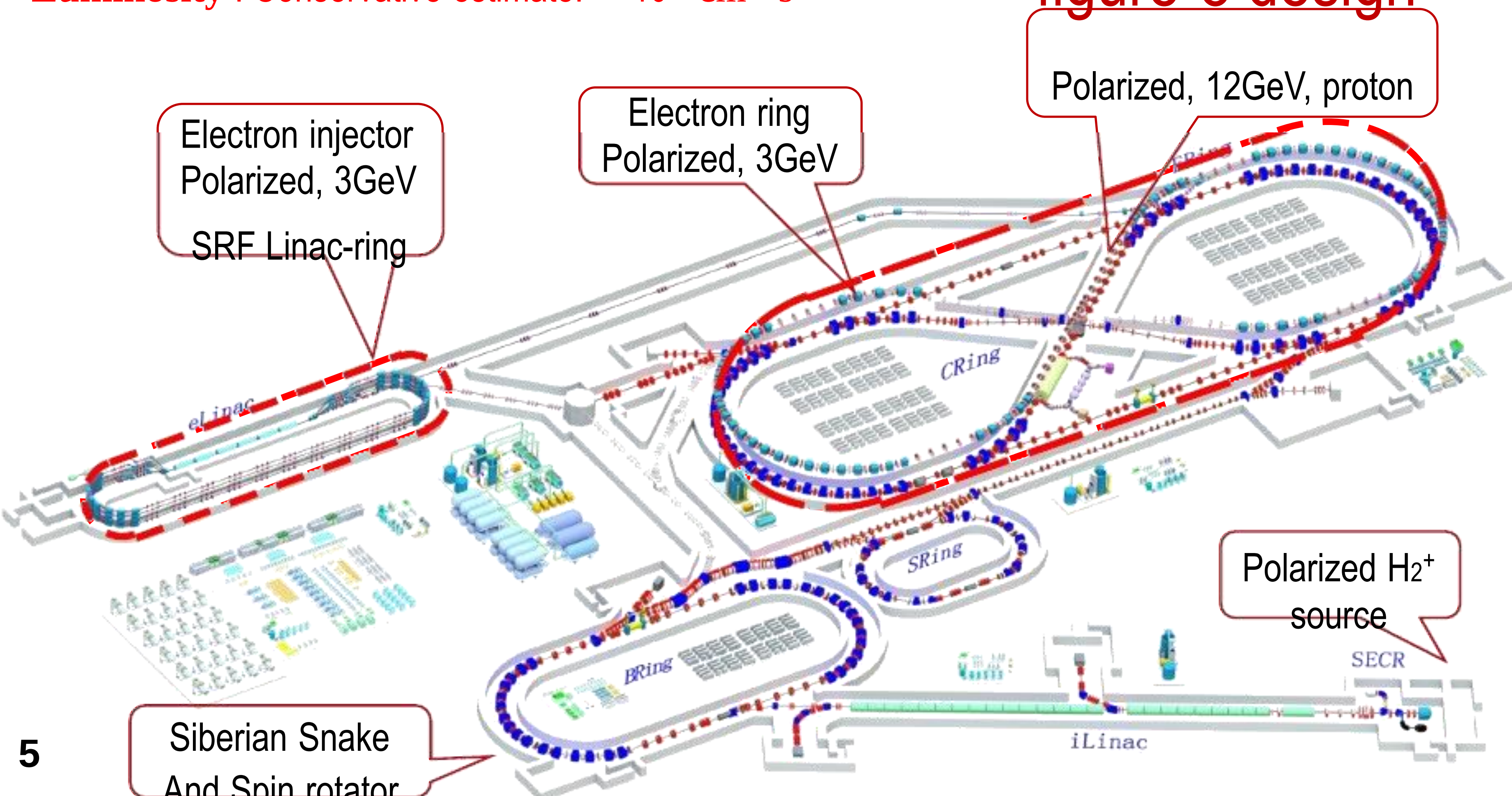
Second phase for HIAF: EIC

- HIAF design maintains a well defined path for EIC
- In HIAF I: EIC Ion pre-Booster $10^{14\sim15}$ ppp → Lower energy EIC (Update +ERL)

See W. L. Zhan's talk@The 8th Workshop on Hadron Physics in China and Opportunities Worldwide

Luminosity : Conservative estimate: $\sim 10^{33}\ cm^{-2}\ s^{-1}$

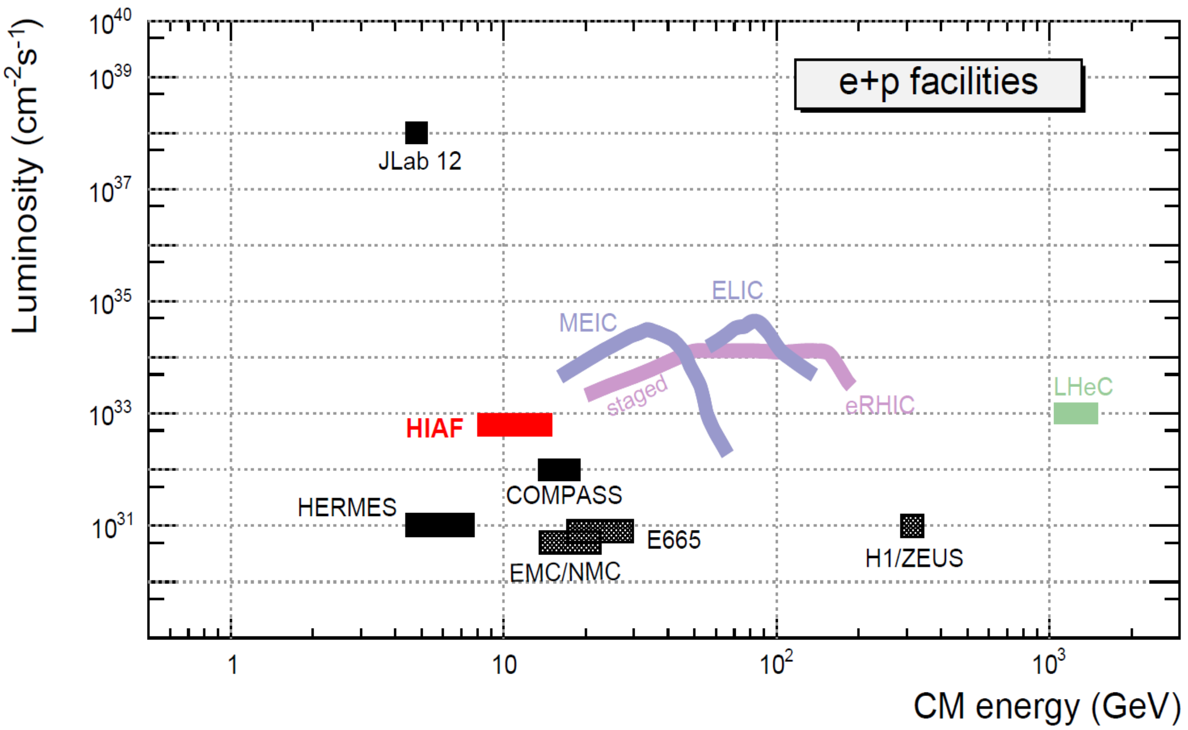
figure-8 design



2. EIC@HIAF Physics

Lepton-Nucleon Facilities

HIAF: e(3 GeV) +p(12~16 GeV), both polarized, L >= 10^{33} cm^{-2}/s^{-1}

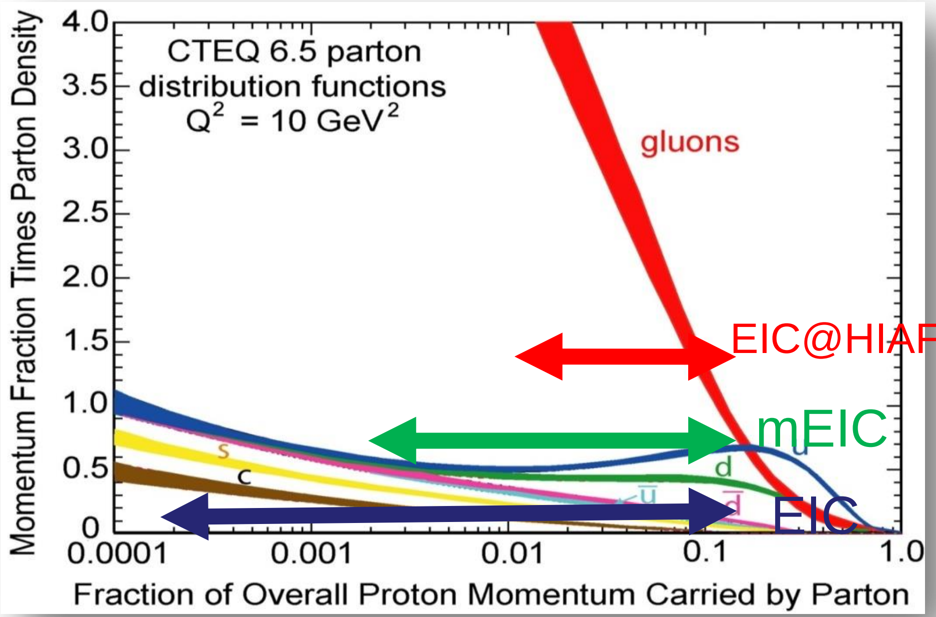


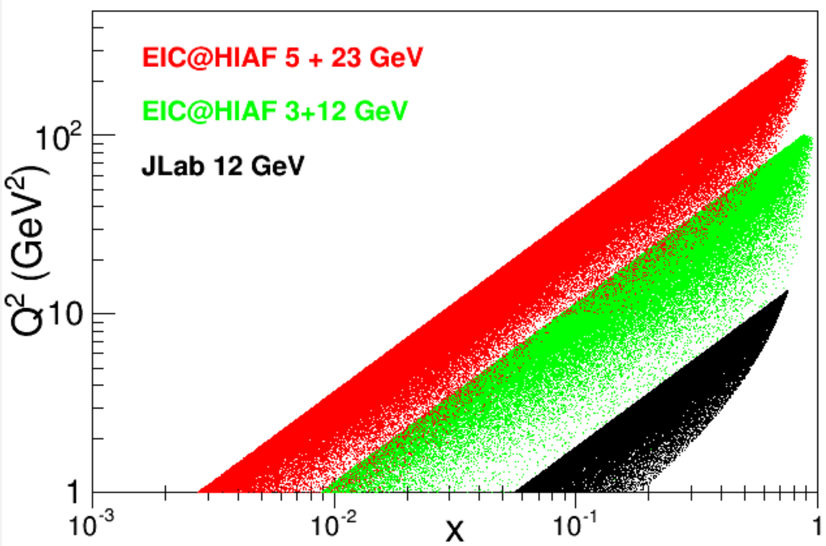
●The energy reach of the EIC@HIAF is significantly higher than JLab12 but lower than the full EIC being considered in US

●COMPASS has similar (slightly higher) energy, but significantly lower polarized luminosity (about a factor of 200 lower, even though the unpolarized luminosity is only a factor of 4 lower)

●HERA only has electron and proton beams collision, but no light or heavy ion beams , no polarized beams and its luminosity is low (10^{31} $cm^{-2}s^{-1}$)

The Landscape of EIC@HIAF





EIC@HIAF : Explore the spin and spatial structure of valence & sea quarks in nucleons

The best region for studying sea quarks ($x > 0.01$) higher Q^2 in valance region, Allows some studies of gluons

Facilities	Main goals
JLab 12 GeV	Valence quark
HIAF-EIC	Sea quark
US and Europe EIC	gluon

Physics Programs at EIC@HIAF

- ***One Main Goal:*** Map the spin-flavor, multi-D spatial/momentum structure of valence & sea quarks

- **Six Golden Experiments**

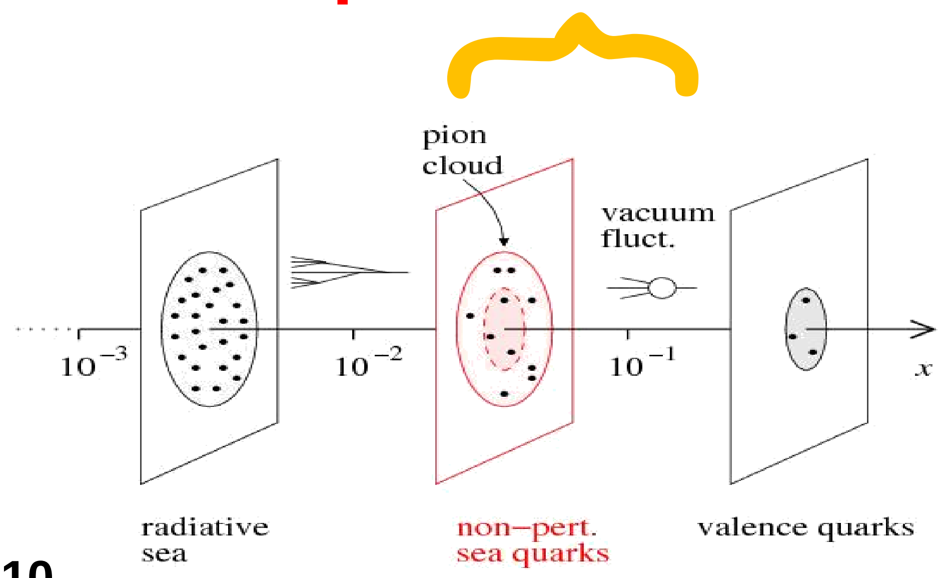
1. **Nucleon spin-flavor structure (polarized sea, Δu Δd Δs)**
2. **GPDs (Deep-Virtual γ/Meson Production, pion/Kaon)**
3. **TMD in "sea quark" region and significant increase of Q^2 & P_T range in valence region**
4. **Pion/Kaon structure functions in the high-x (valence) region**
5. **e-A to study hadronization**
6. **EMC-SRC in e-A**

Proposed by international and Chinese High energy nuclear physics communities

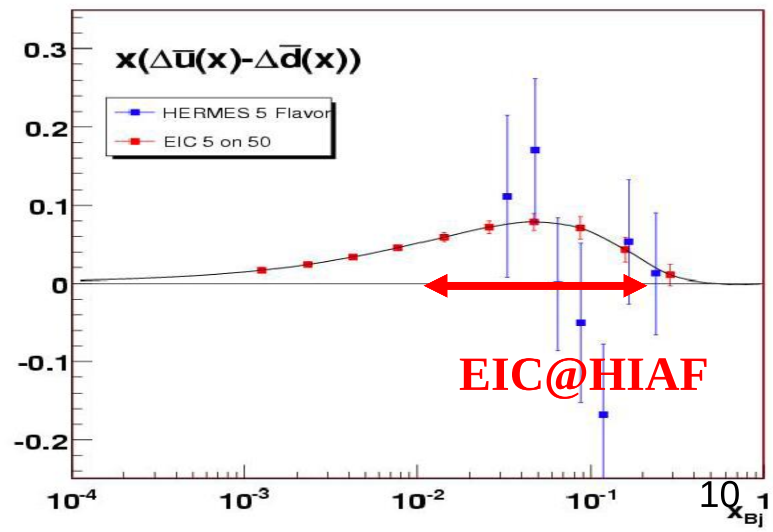
1. Spin-Flavor Study at EIC@HIAF

- **EIC@HIAF, combination of energy and luminosity**
  Significant improvement for $\Delta\bar{u}$, $\Delta\bar{d}$ from DIS

Unique opportunity to improve Δs data



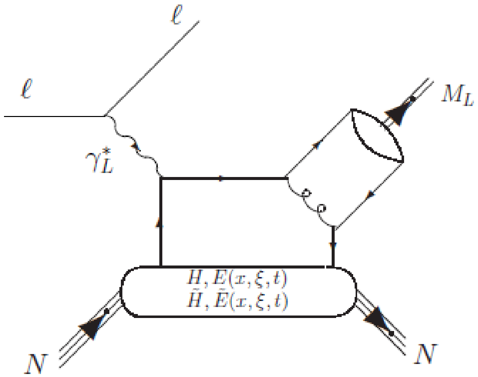
Sea Quark Polarization



2. GPD Study at EIC@HIAF

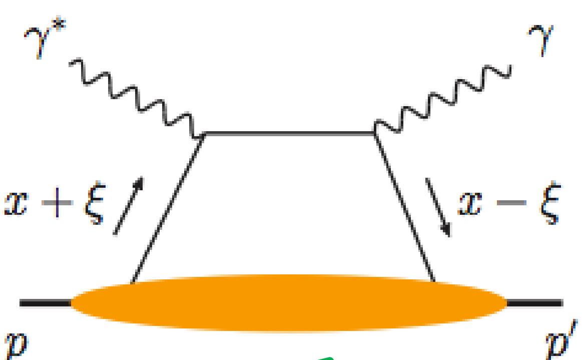
- Low energy: DVCS
- At high energy (EIC): DVCS & DVMP

- flavor decomposition needs DVMP
- energy reaches Q^2 > 5~10 GeV^2, scaling region for exclusive light meson production
- JLab12 energy is not high enough to have clean meson deep exclusive process
- EIC@HIAF: significant increase in the kinematic range for DVCS; Unique opportunity for DVMP (and pion/Kaon)

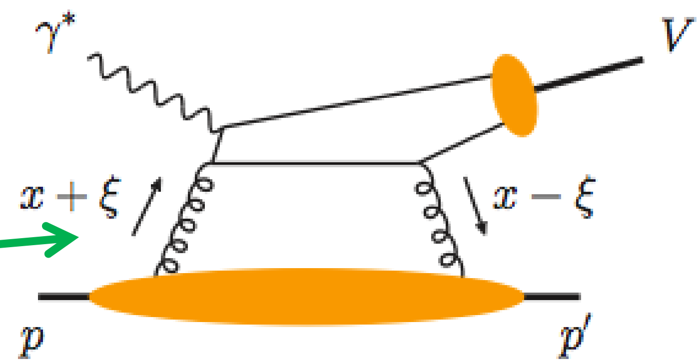


Meson

DVCS



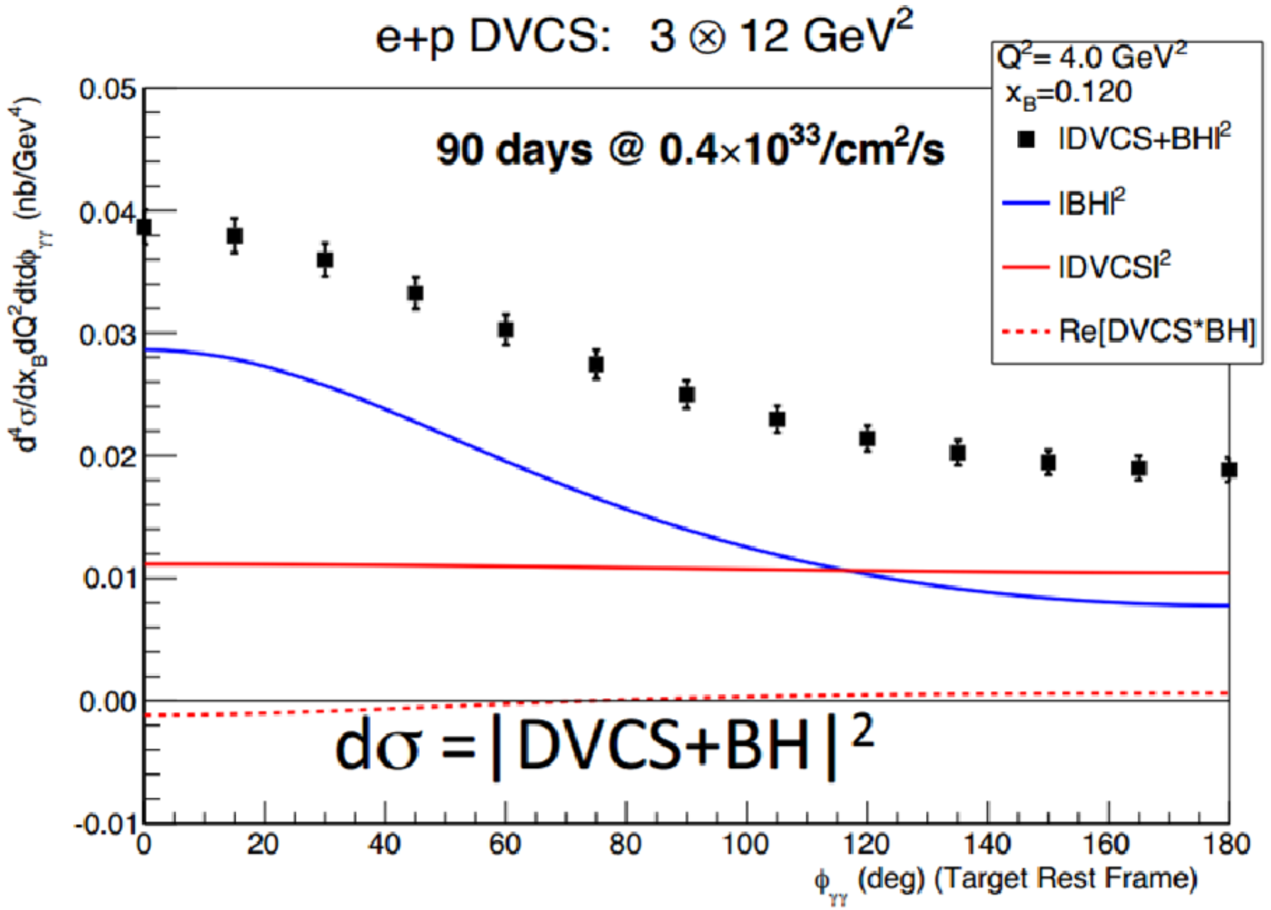
DVMP



GPD

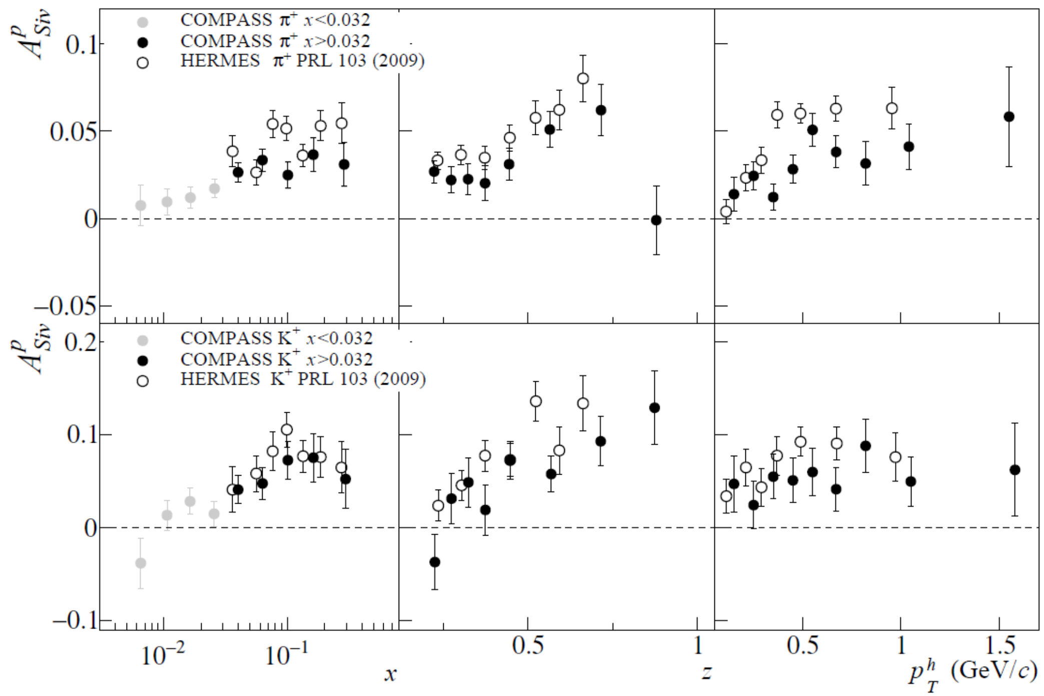
DVCS simulations

3 x 12 GeV



Statistic error for EIC@HIAF is small!

3. TMD Sivers From COMPASS and HERMERS



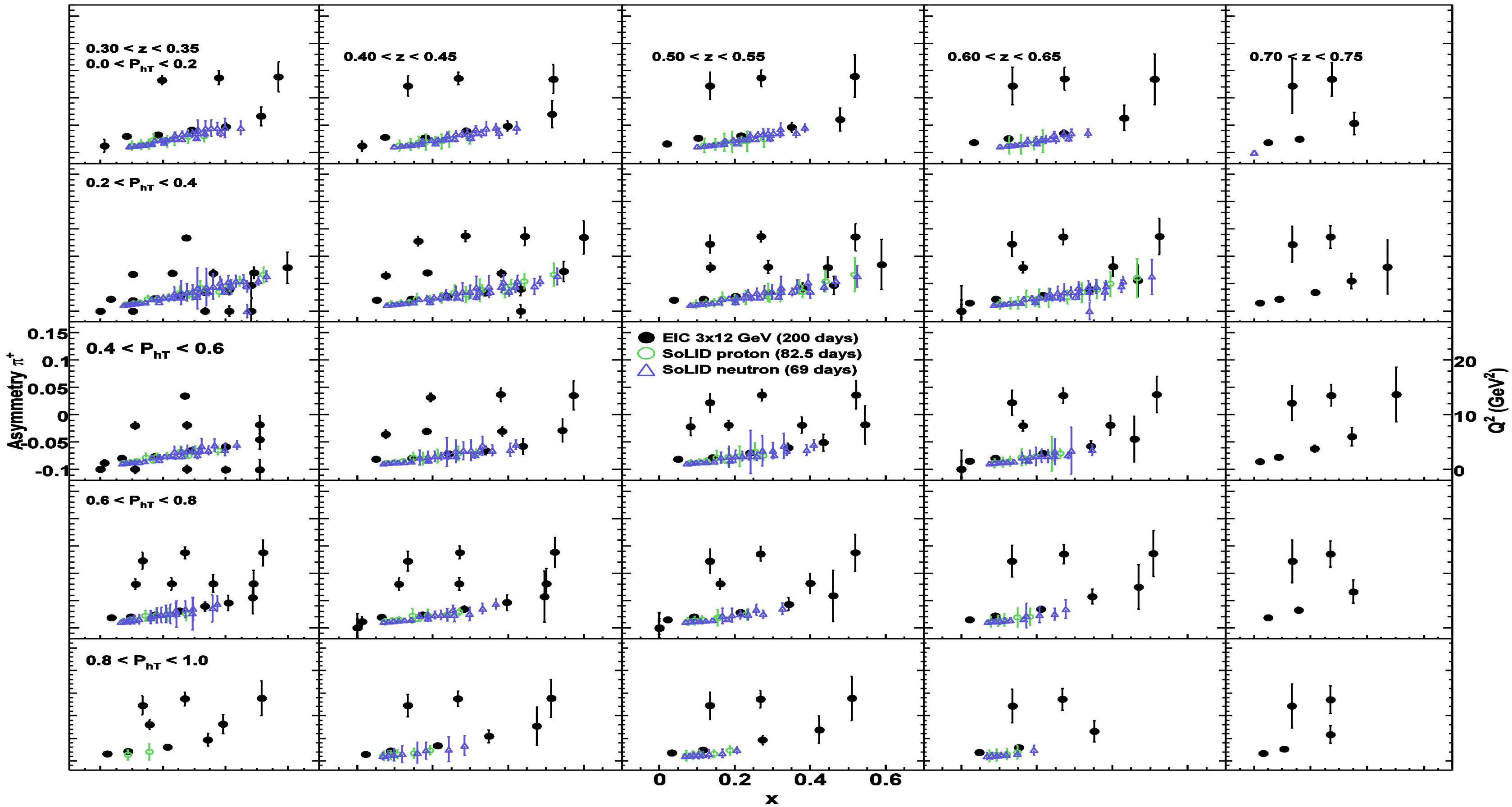
●Understanding the TMDs is certainly a complex task which demands major efforts in different laboratories in studying many different processes ranging over a wide kinematic region

●Many new and interesting results were obtained in last decade. Basic contributions came from the COMPASS,HERMES and JLab experiments

●**Impact of the EIC@HIAF**:

Among the unique features of colliders is the sensitivity for an exploration of the Sivers function for sea quarks, which are expected to play an important role in the lower x region ($x \sim 10^{-2}$)

The TMD simulation: Projections for SIDIS Asymmetry π^+



π^+ Sivers asymmetries for all kinematic bin in terms of different x and Q^2 bin

(x, Q^2, z and P_T)

Green (Blue) Points: SoLID projections for polarized NH_3 (^{3}He/n) target

Luminosity: 10^{35} (10^{36}) (1/cm^2/s); Time: 120 (90) days;

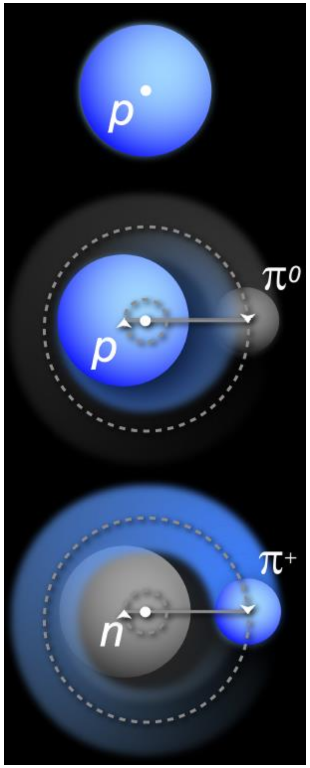
By Haiyan Gao (Duke)

Black points: EIC@HIAF projections for 3 GeV e and 12 GeV p

Luminosity: 4 x 10^{32} /cm^2/s; Time: 200 days

4. π/K Parton Distribution Functions in Valence Quark Region

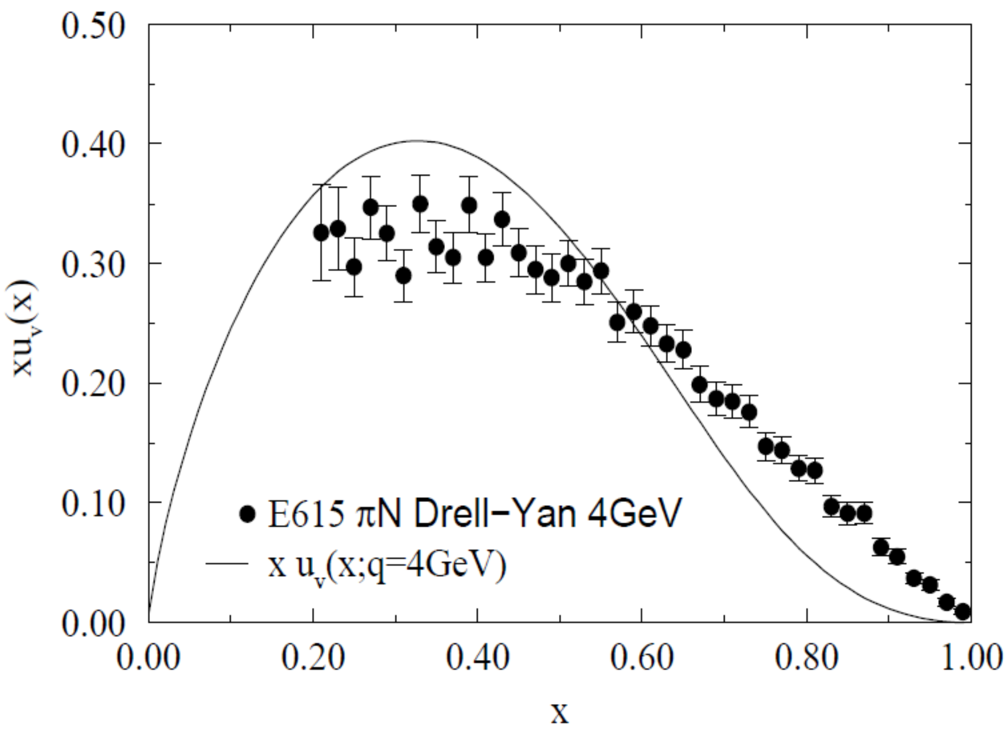
- The parton distributions of nucleons are now well determined, however, much less is known about the PDFs of other hadrons
- The **π**, being the lightest meson, is particularly interesting not only because of its importance in chiral perturbation theory, but also because of its importance in explaining the quark sea in the nucleon and the nuclear force in nuclei
- Pionic sea and gluon densities remains unconstrained in experiment
- **Theories:**
  - Dyson-Schwinger equations
  - Nambu-Jona-Lasinio model
  - Constituent quark model
  - Lattice QCD (lower moments)
  - Instanton model
  - perturbative QCD prediction
  - ……
- **Experiments:**



Drell-Yan processes: NA3, NA10, E615, COMPASS II, J-PARC,....

4. π/K Parton Distribution Functions in Valence Quark Region

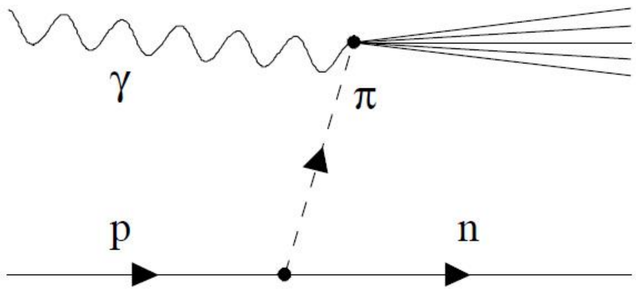
Discrepancy exists between the data and the theoretical calculation at very high x. Another measurement using a different technique at high x would be important

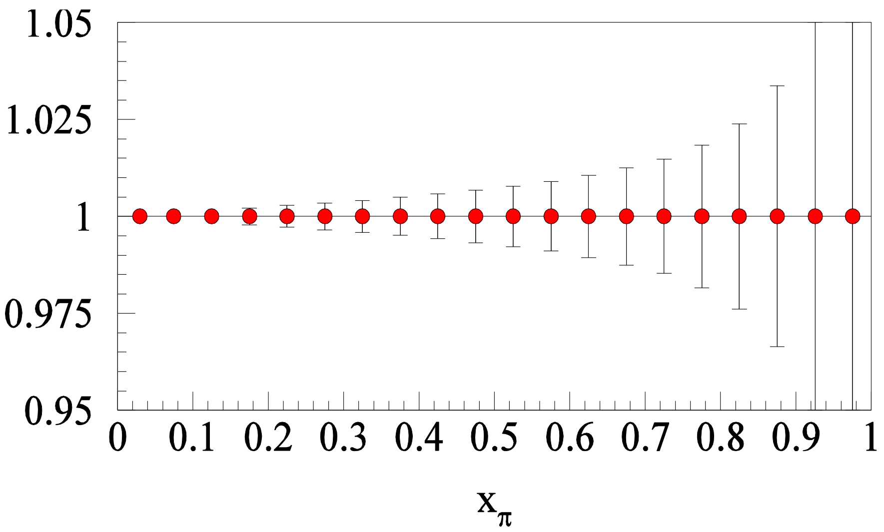


π structure function:

Drell-Yan vs. DSE

4. π/K Parton Distribution Functions in Valence Quark Region





π structure simulation for EIC@HIAF

- 3 GeV e and 12 GeV p
- Luminosity: 5 x 10^{32} /cm^2/s;
- Time:10^6 seconds

Paul Reimer (Argonne)

- EIC@HIAF will be able to extract π PDFs with a high precision
- These, together with the Kaon PDFs, will provide benchmark tests of theoretical calculations, such as Lattice QCD (moments) and the DS equations

Hadron Physics for EIC@HIAF?

- The e^+e^- machine, such as Belle, BarBar and BES, search for exotic new charmonium states: X, Y and Z particles
- The JLab12 GlueX searches for gluon excitation, as well as Search for new hadron states
- **The EIC@HIAF, as e-p machine, higher CM energy than Jlab12 GeV Upgrade, should have some advantages**
- The potential of discovery of hidden charm baryon resonances via photoproduction was discussed in 2014 (Yin Huang, Jun He, Hong-Fei Zhang, and Xu-Rong Chen. Discovery potential of hidden charm baryon resonances via photoproduction. J. Phys., G41(11):115004, 2014)

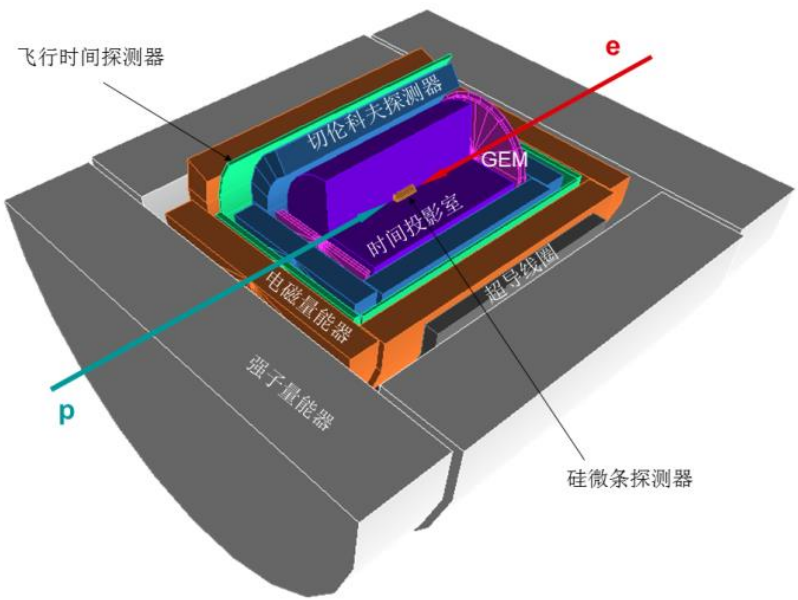
JLab PR12-16-007: A Search for the LHCb Charmed 'Pentaquark' using Photo-Production of J/psi at Threshold in Hall C at Jefferson Lab

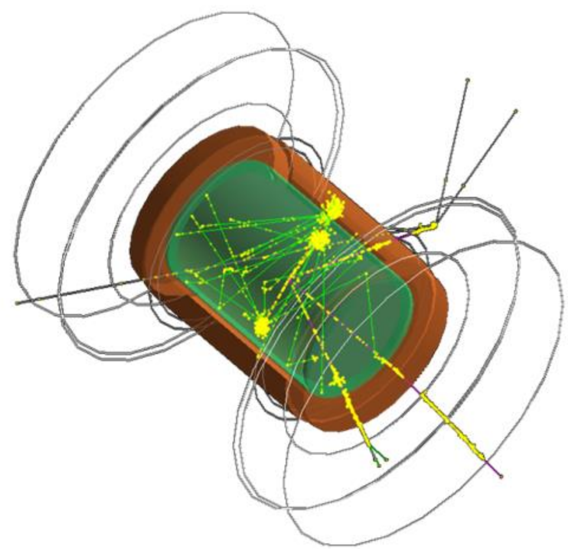
Aapproved with an 'A' rating and a 'high-impact' label by the Jefferson Lab PAC 44 in July 2016. The experiment was awarded 11 days of beam time.

3. Current Status and Summary

Design Ideas

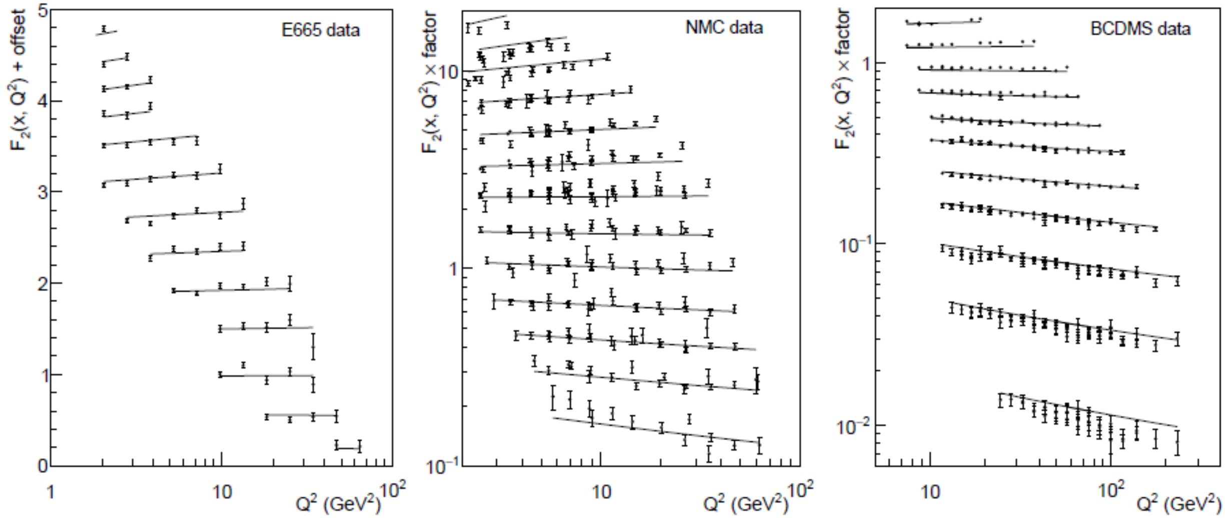
- We have been worked on R&D of EIC@HIAF since 2012
- Proton and electron polarimetry measurements
- Detector systems: TPC, Cherenkov detectors, Solenoid, Electromagnetic calorimeters, and Hadron calorimeters.





IMParton parton distribution functions

- **We introduce a dynamical parton distribution functions, which is from a global analysis of DGLAP equations with nonlinear corrections**

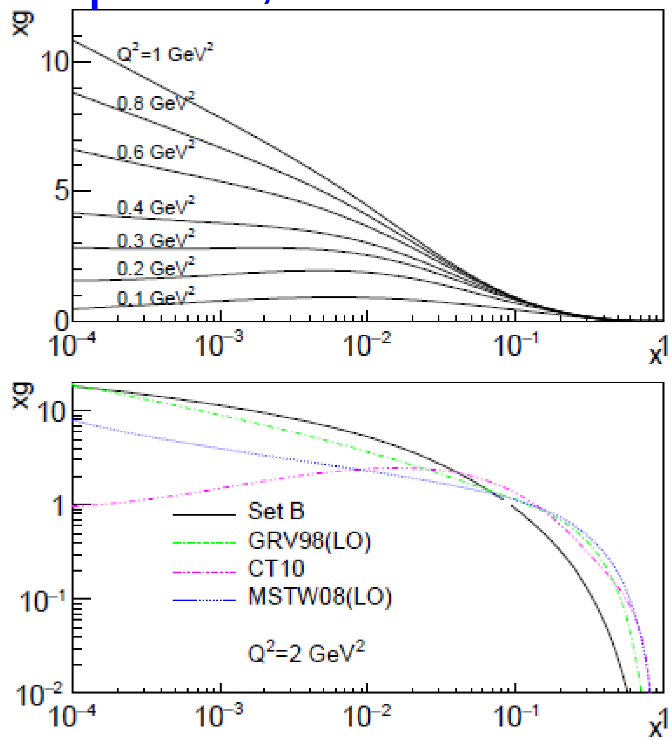


Reference: **arXiv:1609.01831**

Download the data: https://github.com/lukeronger/IMParton

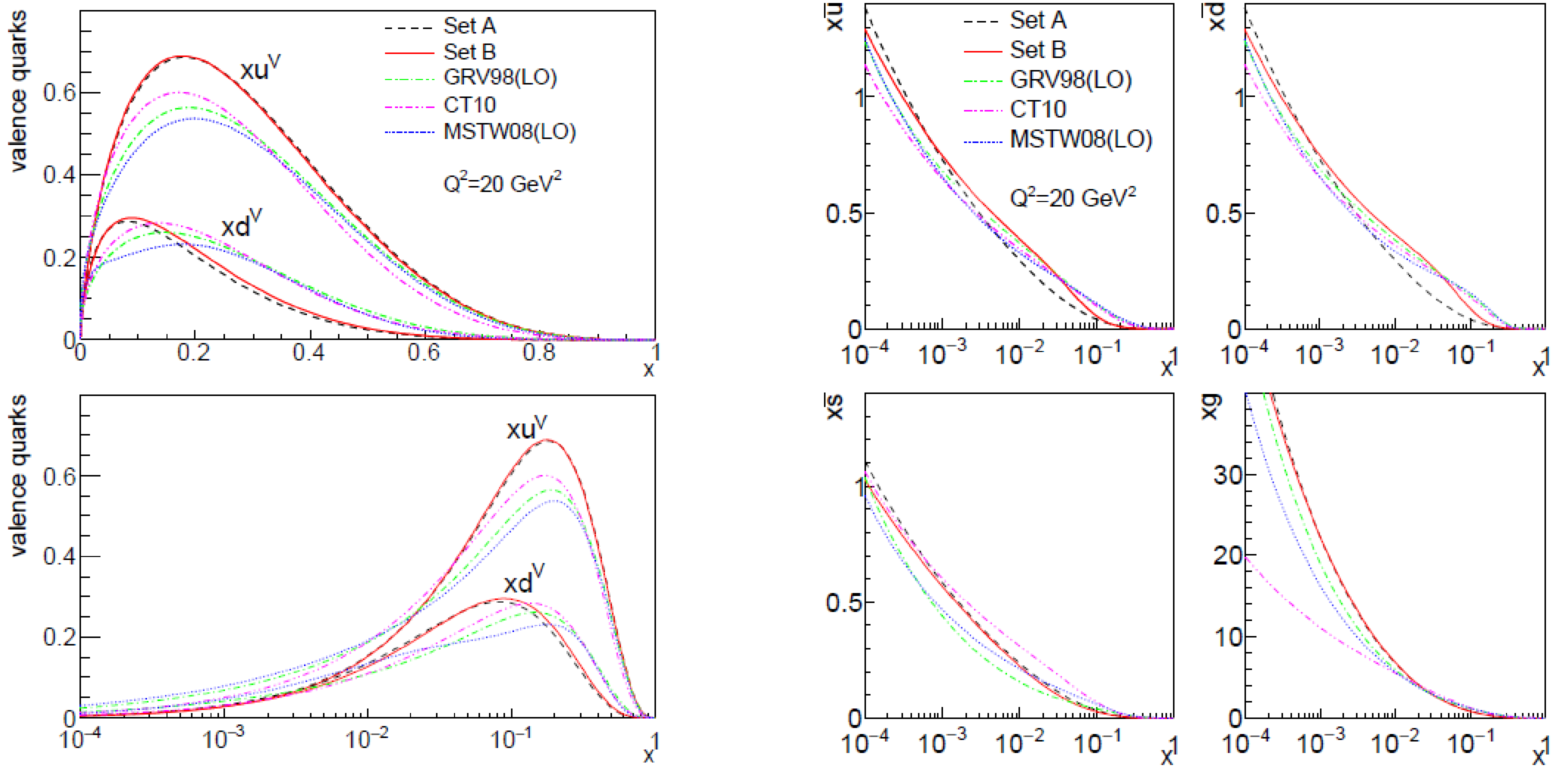
IMParton parton distribution functions

- The initial parton distributions are directly connected to the quark model and the intrinsic sea of small quantity. Three valence quarks input is realized
- There is no initial gluon in our approach. The gluon is purely dynamical radiated from valence quarks, which is better constranted at small x
- The dynamical gluon is aways positive at low Q^2 even around **0.1 GeV²**



IMParton parton distribution functions

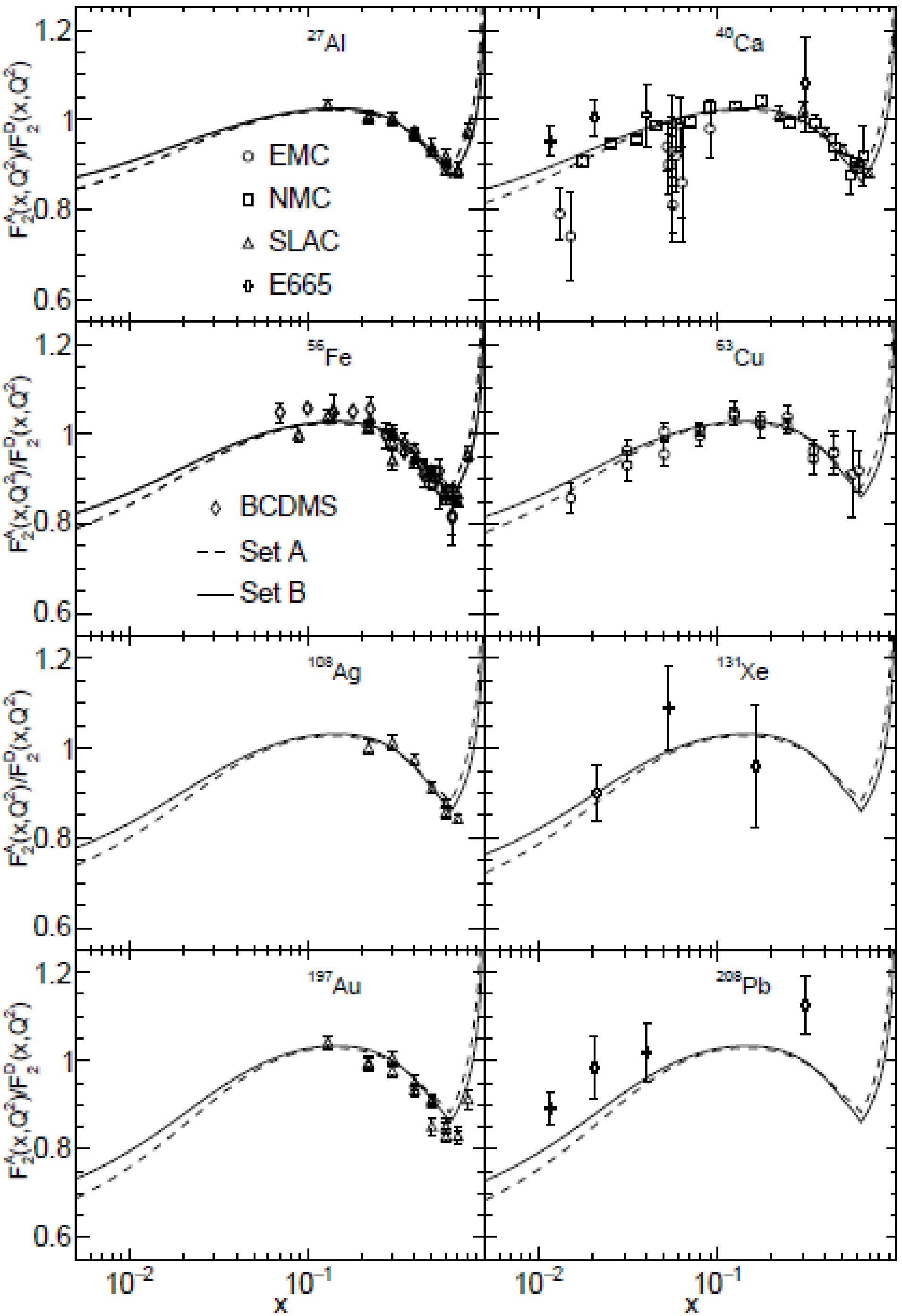
- The parton recombination corrected DGLAP equations are considered to evolve the parton distributions from low resolution scale to high resolution scale
- The obtained valence quark and sea quark distributions are compatible with other widely used PDFs at high Q^2



Nuclear IMParton

A global analysis of nuclear parton distributions is performed based on an extended dynamical parton model, which has zero gluon density at the input scale.

Parton-parton recombination for nuclear shadowing, nucleon swelling for the EMC effect, and Fermi motion smearing are used together to model the complicated x-dependence of nuclear modification factor.



Reference: **arXiv:1611.03670**
Download the data:
https://github.com/lukeronger/nIMParton

Nuclear IMParton

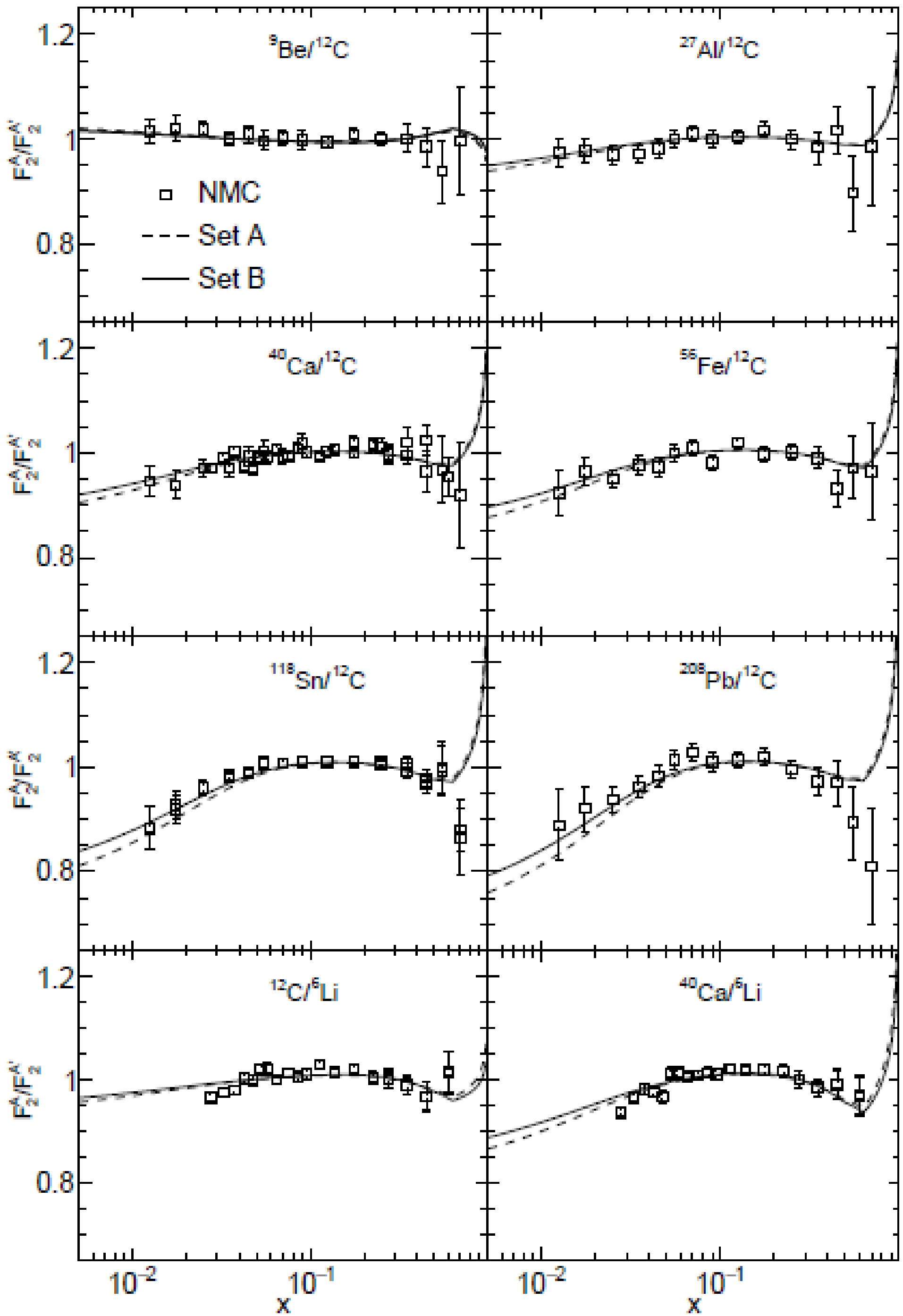
The global analysis result:
$\chi^2/N = 966/701 = 1.38$

Nuclear dependence:

$$Q^2 \frac{dxf_g(x,Q^2)}{dQ^2} = \frac{\alpha_s(Q^2)}{2\pi}[P_{gq}\otimes\Sigma + P_{gg}\otimes f_g]$$
$$-A_{eff}\frac{\alpha_s^2(Q^2)}{4\pi\tilde{R}^2Q^2}\int_x^{1/2}\frac{dy}{y}xP_{gg\to g}(x,y)[yf_g(y,Q^2)]^2$$

Parton-parton recombination enhancement in nucleus,
A_{eff} linearly increase with the size of a nucleus.

Nucleon swelling linearly increase with the residual strong interaction energy(RSIE), $\frac{R_A}{R_p} = 1 + \alpha \times RSIE$

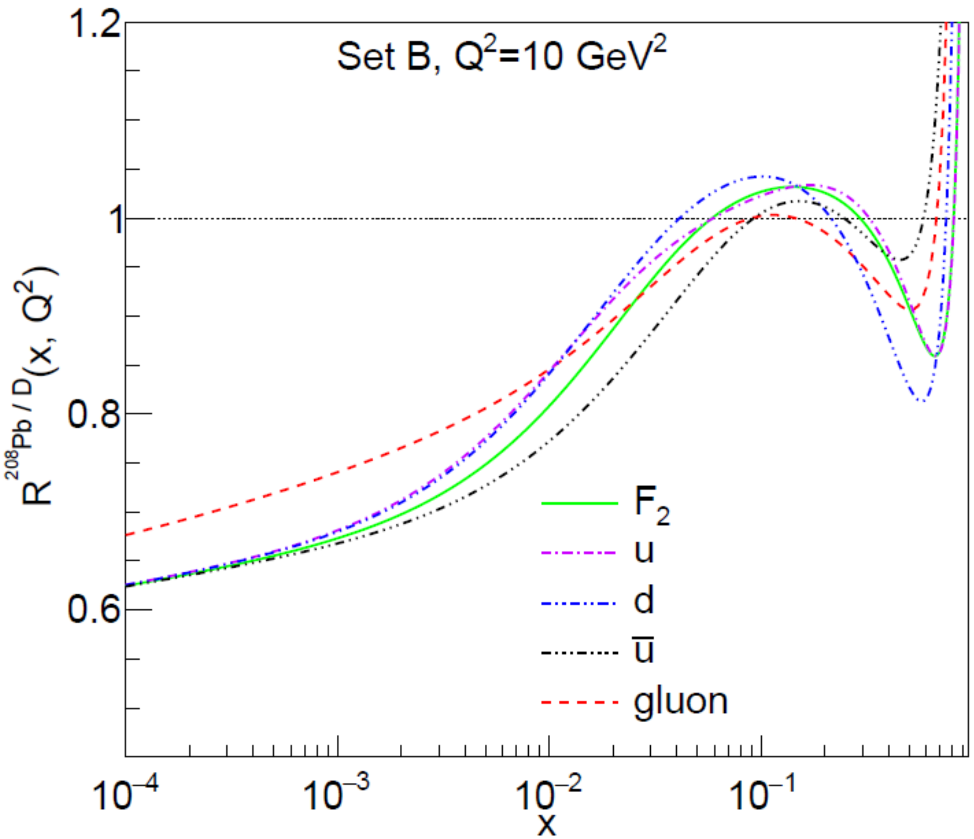


Nuclear IMParton – flavor dependence

In the dynamical parton model, the flavor-dependence of nuclear modification is weak (see right figure).

For gluon: the gluon shadowing is a little weaker than that of quarks. The anti-shadowing effect of gluon is very weak.

The EMC effect:
The valence quarks have the strongest EMC effect. And the strength of the EMC effect of gluon is stronger than that of sea quarks.

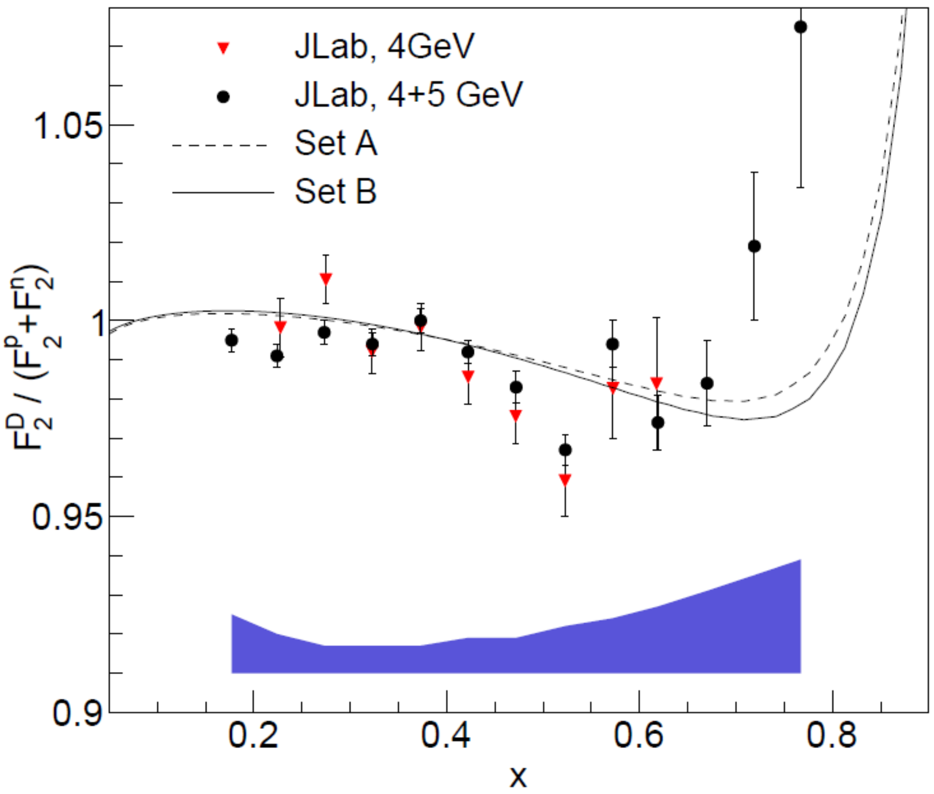


Nuclear IMParton – prediction of nuclear correction of deuteron

The nuclear correction of deuteron is predicted from the obtained free parameters in the global analysis.

In the EMC effect region, the prediction by the dynamical parton model is in agreement with the state-of-art measurement at JLab.

The predicted Fermi motion smearing is weaker than the data. Fermi momentum of 87 MeV for deuteron used in the calculation maybe is small, since the N-N short-range correlation is not considered.

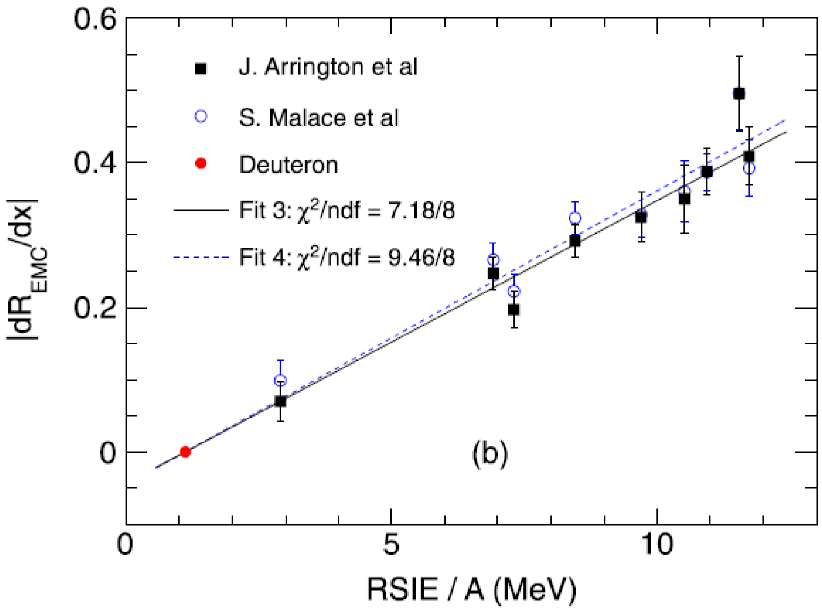


Nuclear dependence of the EMC effect

$$RSIE(A,Z) = B(A,Z) + a_c Z(Z-1)A^{-1/3}.$$

RSIE is residual strong interaction energy (nuclear binding with Coulomb interaction subtracted)

An amazing linear correlation is found between the EMC slope and residual strong interaction energy per nucleon. (ref. **arXiv:1406.7622**, Phys. Lett. B 743 (2015) 267)



$$\left|\frac{dR_{EMC}}{dx}\right| = \left(\frac{RSIE}{A\ \mathrm{MeV}} - 1.112\right) \times (0.041 \pm 0.002).$$

Predictions →

Nucleus	$\lvert dR_{EMC}/dx \rvert$
^{3}H	0.070 ± 0.004
^{3}He	0.073 ± 0.004
^{4}He	0.254 ± 0.013
^{6}Li	0.189 ± 0.010
^{7}Li	0.197 ± 0.010
^{9}Be	0.238 ± 0.012

Nucleus	$\lvert dR_{EMC}/dx \rvert$
^{10}B	0.247 ± 0.012
^{11}B	0.262 ± 0.013
^{12}C	0.301 ± 0.015
^{40}Ca	0.386 ± 0.019
^{48}Ca	0.373 ± 0.019
^{63}Cu	0.408 ± 0.020

Nuclear dependence of N-N short-range correlations

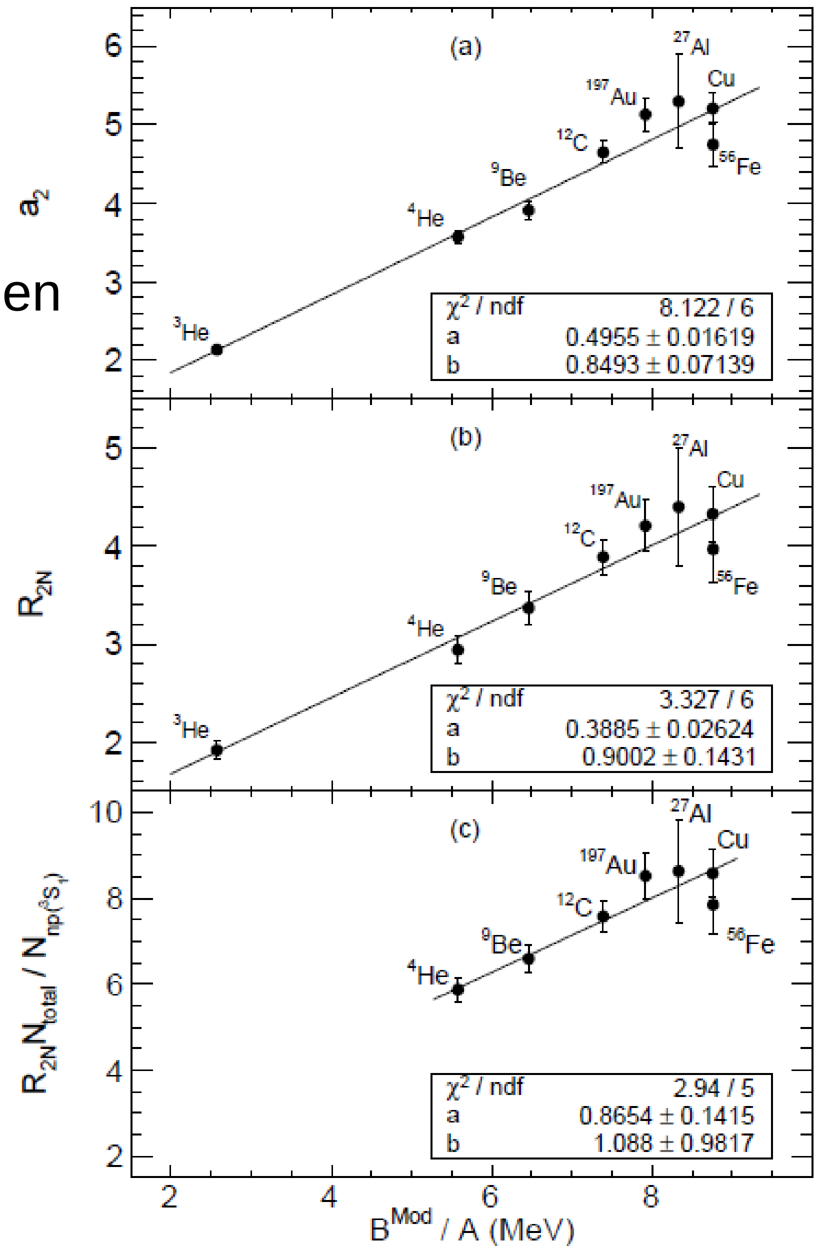
A modified binding energy with no pairing contribution is defined as,

$$B^{\mathrm{Mod}}(A,Z) = B(A,Z) - \delta,$$

An amazing linear correlation is found between B^{Mod} and nucleon-nucleon short-range correlatoins. (see right fig.)

$$a_2 = (0.496 \pm 0.017)\frac{B^{\mathrm{Mod}}}{A\ \mathrm{MeV}} + (0.849 \pm 0.072),$$

$$R_{2N} = (0.389 \pm 0.027)\frac{B^{\mathrm{Mod}}}{A\ \mathrm{MeV}} + (0.9 \pm 0.15).$$



Predictions ↓ ref. **arXiv:1610.07000**

nucleus	B/A (MeV)	B^{Mod}/A (MeV)	a_2	R_{2N}
^{3}H	2.827	2.827	2.25±0.12	2.00±0.23
^{6}Li	5.332	6.148	3.90±0.18	3.29±0.32
^{10}B	6.475	6.854	4.25±0.19	3.57±0.34
^{14}N	7.476	7.705	4.67±0.21	3.90±0.36
^{40}Ca	8.551	8.504	5.07±0.22	4.21±0.38
^{48}Ca	8.667	8.631	5.13±0.22	4.26±0.38

Summary

- The first phase of HIAF was approved in 2015!
- We are working on R&D for EIC key techniques + physics/simulations of the Golden Experiments.
- Now civil construction for HIAF is going on in Huizhou. The budget for electron beam will come from Chinese central government or the local government.
- EIC@HIAF will open up a new window to study the nucleon structure, especially in the sea quark region.

Thanks for your attention!